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Temporal velocity changes in the deep crust driven by aseismic afterslip of the great Sumatra earthquakes

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Temporal variations of seismic velocity associated with earthquakes are useful to elucidate how the Earth's crust responds to small stress perturbations and to monitor pre-earthquake fault movement in situ. Previous studies indicate temporal velocity changes located at shallow depth in association with ground shaking. However, it is unclear how material at high confining pressure behaves. Here we study temporal velocity changes associated with the great 2004 Sumatra (Mw 9.2) and 2005 Nias (Mw 8.7) earthquakes, using repeating earthquakes. Observed temporal velocity changes reveal several major features: (1) lag-time of high frequency coda waves grows monotonically as a function of lapse time for the 2005 repeating earthquake sequences; whereas lag-time of high frequency coda waves fluctuates around zero and sometimes negative against lapse time measured from the 2004 repeating earthquake sequences; (2) the amplitude of lag-time of S-wave coda is much larger than that of P-wave coda for the first few measurements immediately after the main shock, and the amplitude of lag-time of S-wave coda displays a more prominent temporal decrease compared to that of P coda, especially for the measurements associated with the great 2005 Nias earthquake; (3) high frequency S-wave coda and long period Rayleigh waves display a progressive temporal velocity recovery as a function of calendar time. In particular, temporal velocity recovery of high frequency coda is similar to the continuous Global Positioning System (GPS) displacement time series at station LHWA near the 2005 Nias earthquake; (3) lag-time of long period Rayleigh waves is over 3-4 times larger than that of long period Love waves. Modelling different types of seismic observations allow us to unambiguously to locate the depth range of temporal velocity changes in the overriding plate. Our modelling results delineate two zones of temporal velocity changes after the 2004 and 2005 great earthquakes. A strong velocity reduction dVs of about -3% within a 250 meters superficial layer, to explain the relative amplitude in lag-time between long period Rayleigh waves and Love waves, is probably induced by co-seismic damage. This temporal velocity recovery corresponds to fault healing near the surface. We also find a weak, localized velocity change dVs of about -0.2% in the depth range of post-seismic afterslip in the overriding crust, to explain the lag-time of high frequency coda. Together with the modelling results of lag-time of high frequency coda and the similarity between velocity recovery of S-wave coda and the GPS displacement time series at LHWA, two independent lines of evidence strongly suggest that the observed temporal velocity changes in the deep crust are predominantly driven by post-seismic afterslip. Deep temporal velocity recovery would correspond to decrease in crack density in the deep crust. Such deep temporal velocity changes are likely to occur under very low effective stress with the presence of saturated fluids, which may dictate the time scale of velocity recovery in the porous crust by diffusing through connecting cracks.